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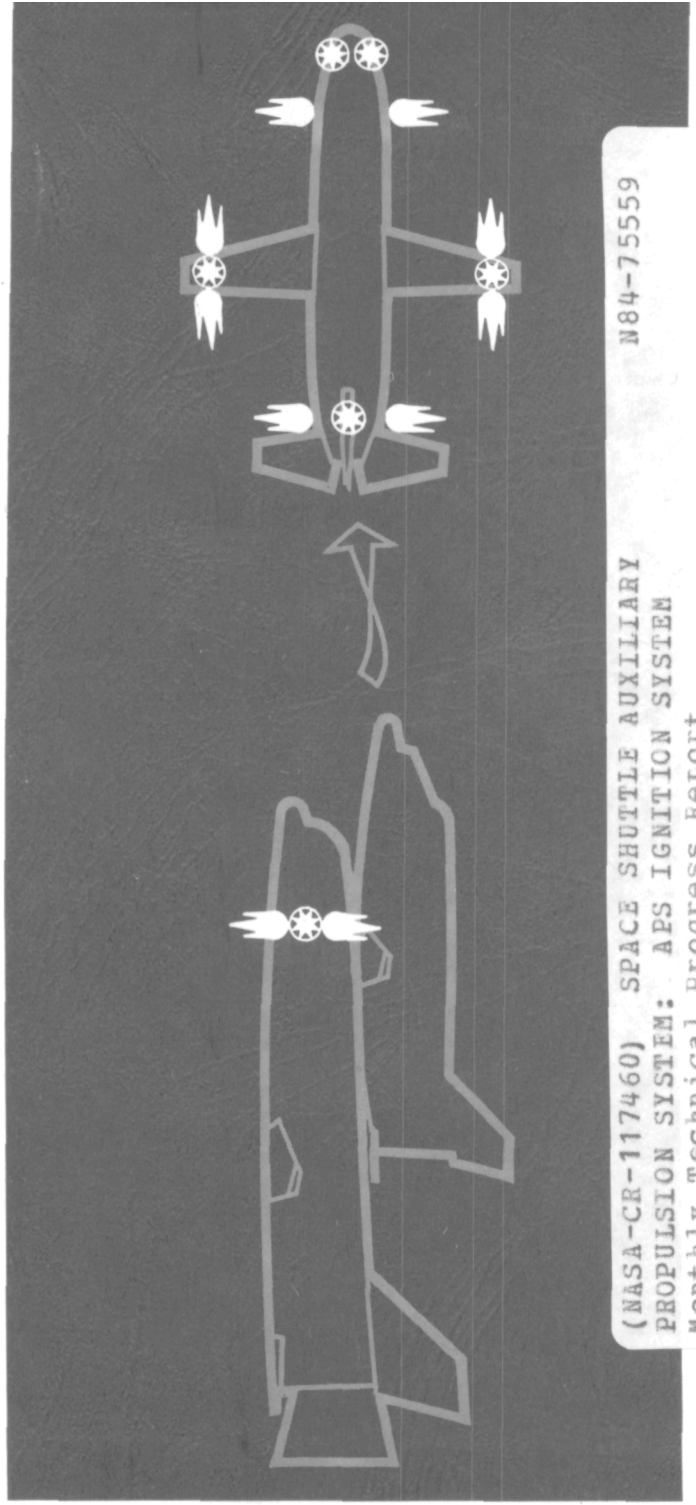

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space shuttle auxiliary propulsion system

NAS3-14351

APS IGNITION SYSTEM

MONTHLY TECHNICAL
PROGRESS NARRATIVE

AUGUST, 1970

Rocketdyne
North American Rockwell

6633 Canoga Avenue,
Canoga Park, California 91304

ASR70-360

SPACE SHUTTLE AUXILIARY PROPULSION IGNITER SYSTEM

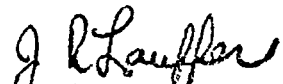
NAS3-14351

FIRST MONTHLY TECHNICAL PROGRESS NARRATIVE

August 1970

Prepared for NASA-Lewis Research Center
Cleveland, Ohio 44135

Prepared by



J. R. Lauffer
Principal Engineer

Approved by

S. J. Domokos
Program Manager

Rocketdyne a Division of North American Rockwell Corporation
6633 Canoga Avenue
Canoga Park, California 91304

INTRODUCTION

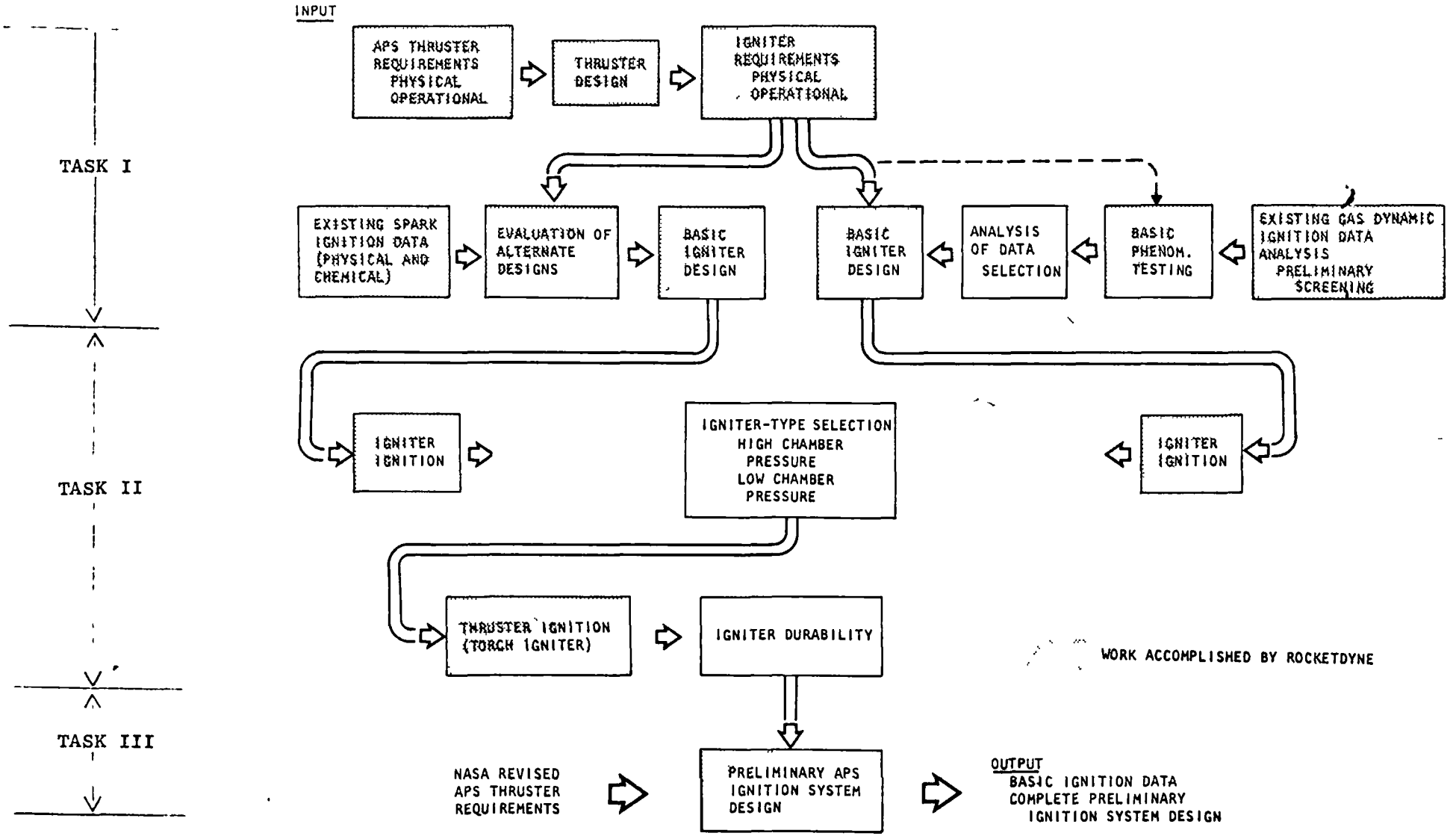
The objective of this program is to obtain basic ignition data on electric spark and resonance tube ignition methods at operating conditions typical of the Space Shuttle APS, and to complete a preliminary design of an optimum ignition system based upon the test results. This technology effort will provide the groundwork input for APS tradeoff studies. It will ensure that specifications established for the APS are realistic and achievable and will provide the basis for an expeditious future engine development program.

The program approach is shown in Fig. 1. The technical effort is conducted in three tasks: Task I - Igniter Design and Fabrication, Task II - Igniter Tests, and Task III - Ignition System Preliminary Design. Task IV includes program management and reports.

This nine month program consists of parallel efforts at the two chamber pressure levels typical for Space Shuttle APS application, 300 psia (206.9 Newton/cm^2) and 15 psia (10.35 Newton/cm^2). Engine thrust level is 1500 pounds (6672 Newtons). The igniter flowrates are approximately 1 percent of the total thruster propellant flowrate.

Contract go-ahead was received 23 July 1970 and efforts during this first report period were devoted primarily to Task I igniter design and fabrication.

IGNITION SYSTEMS PROGRAM SEQUENCE



Rocketdyne
North American Rockwell

Figure 1

DESCRIPTION OF PROGRESS

TASK I - IGNITER DESIGN AND FABRICATION

During this task, analysis and design efforts will be conducted for igniters capable of providing reliable ignition for hydrogen/oxygen thrusters operating at the two design points. The efforts on the spark igniter and the auto-igniter will be conducted in parallel. The task schedule and major milestones are shown in Fig. 2.

Alternate spark igniter injector and plug location will be evaluated on cold flow tests during Task I to obtain a fundamental understanding of mixture ratio and gas velocity at candidate plug locations for the range of operational variables.

Electrical system equipment will also be designed, fabricated and laboratory tested during Task I. This equipment includes a variable energy power supply, spark plugs, and a flight-type fixed-energy integrated plug/converter. The variable energy power supply and different spark plug gap configurations will be evaluated by laboratory tests during Task I and will be used to establish minimum energy requirements during the initial Task II testing. The design of the flight-type fixed-energy integrated plug/converter will be based upon these test results. This integrated plug will be demonstrated on the igniter durability testing.

During Task I, analysis and design efforts will also be conducted for resonance igniters capable of providing reliable ignition for hydrogen-oxygen thrusters operating at the two design points.

Basic igniter configurations have been established and will be evaluated during Task I on well-instrumented laboratory-type tests using GH_2/GO_2 propellants. The effects of geometric and operational variables on the ability to obtain elevated temperatures and the effects of propellant injection and sequencing on the ability to obtain and sustain combustion will be evaluated.

SPACE SHUTTLE - A. P. S. IGNITION SYSTEM (SCHEDULE & MILESTONES)

Form 600-U-4 Rev 3-63

DIETERICH-POST CLEARPRINT 1000H

Figure 2

PREPARED BY
DATE 23 June 1970 BY J. Lauffer
Revised: 29 July 1970

The igniter designs will be submitted for NASA approval prior to initiation of fabrication.

No effort is planned for the design of the thruster injectors and heat sink thrust chambers. This program will use available Rocketdyne 1500-pound-thrust hardware. A high pressure (300 psia) injector and heat sink thrust chamber and a low pressure (15 psia) injector and heat sink thrust chamber have been designed, fabricated, and checkout tested.

SPARK IGNITER

During this report period the major effort on this task was devoted to cold flow hardware design and fabrication, cold flow test program planning, spark exciter design and spark plug design.

Cold Flow Hardware Design and Fabrication

The two high pressure spark igniter cold flow configurations are shown in Fig. 3 and 4. A four on one (fuel on oxidizer) configuration similar to that evaluated on Rocketdyne IR&D and NASA Contract NAS3-14352 has been designed and fabricated. Testing using gas sampling and zone radiometry techniques will be conducted during the next report period.

The second high pressure design (Fig. 4) is similar to the J-2 ASI. A single element (self impinging oxidizer) is placed at the head end of the igniter and the fuel is injected tangentially through eight orifices downstream of the oxidizer. The major portion of the fuel film cools the igniter walls. A small portion of the fuel recirculates to the head end of the igniter providing a low velocity high mixture ratio region in which to locate the spark plug This hardware design has been completed and fabrication has been initiated Testing on this igniter will be limited to gas sampling techniques since the nature of the flow field (recirculation) and the hardware design prohibit the use of zone radiometry.

REVISIONS			
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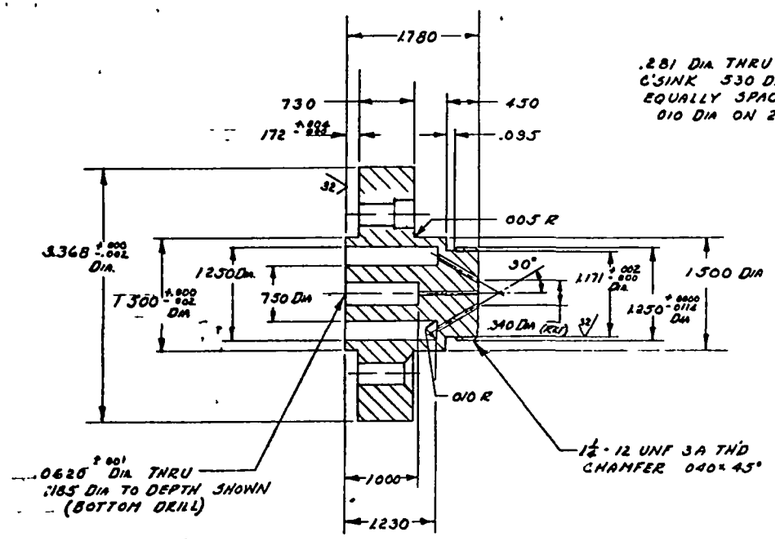
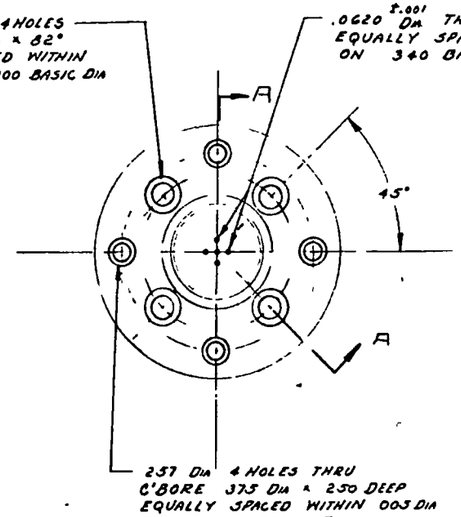
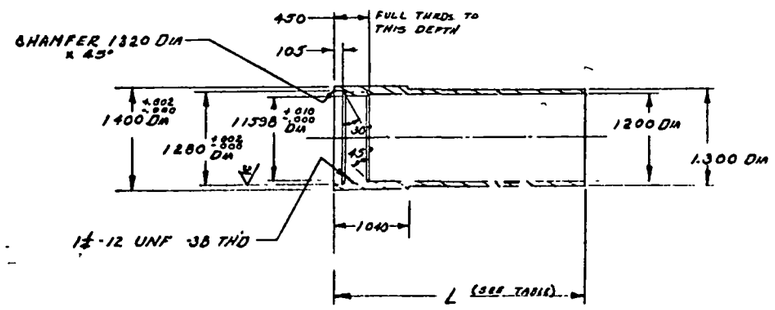


SECTION AA


.281 Dia THRU 4 HOLES
C'SINK .530 Dm x 82°
EQUALLY SPACED WITHIN
.010 Dia ON 2.100 BASIC Dia
.0620 Dia THRU 4 HOLES
EQUALLY SPACED WITHIN .002 Dia
ON .340 BASIC Dia
A
45°
A
.257 Dia 4 HOLES THRU
C'BORE .375 Dia x .250 DEEP
EQUALLY SPACED WITHIN .003 Dia
ON 2.600 BASIC Dia

-003 INJECTOR
MAT'L ~ 6061 T-6 ALUM ALLOY



TABLE

CHAMBER	"L"
1	.430
2	1.040
3	2.225
4	3.410

-005 CHAMBER
MAT'L ~ 321 STAINLESS

2. THREAD PER MIL-S-7742
1. MACHINE PER RAO 103-002

NOTE: UNLESS OTHERWISE SPECIFIED

Figure 3

HEAT TREAT	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH 125 MACH. SURF ROUGHNESS TOLERANCES ON ANGLES ± 0° 30' DECIMALS XX ± .03 XXX ± .010 HOLES NOTED "DRILL"	DWN J P FLOERER DATE 8/1470 CHK DATE DSGN J. FLOERER MATL STRUCT	Rocketdyne North American Rockwell — Canoga Park, California — McGregor Texas
FINISH			IGNITER ~ INJECTOR AND CHAMBER APS
MATL NOTED	DO NOT SCALE PRINT	DESIGN ACTIVITY APVD M J Heller DATE 8-17-70	SIZE D · CODE IDENT NO. 02602 · DRAWING NO. R5002181X
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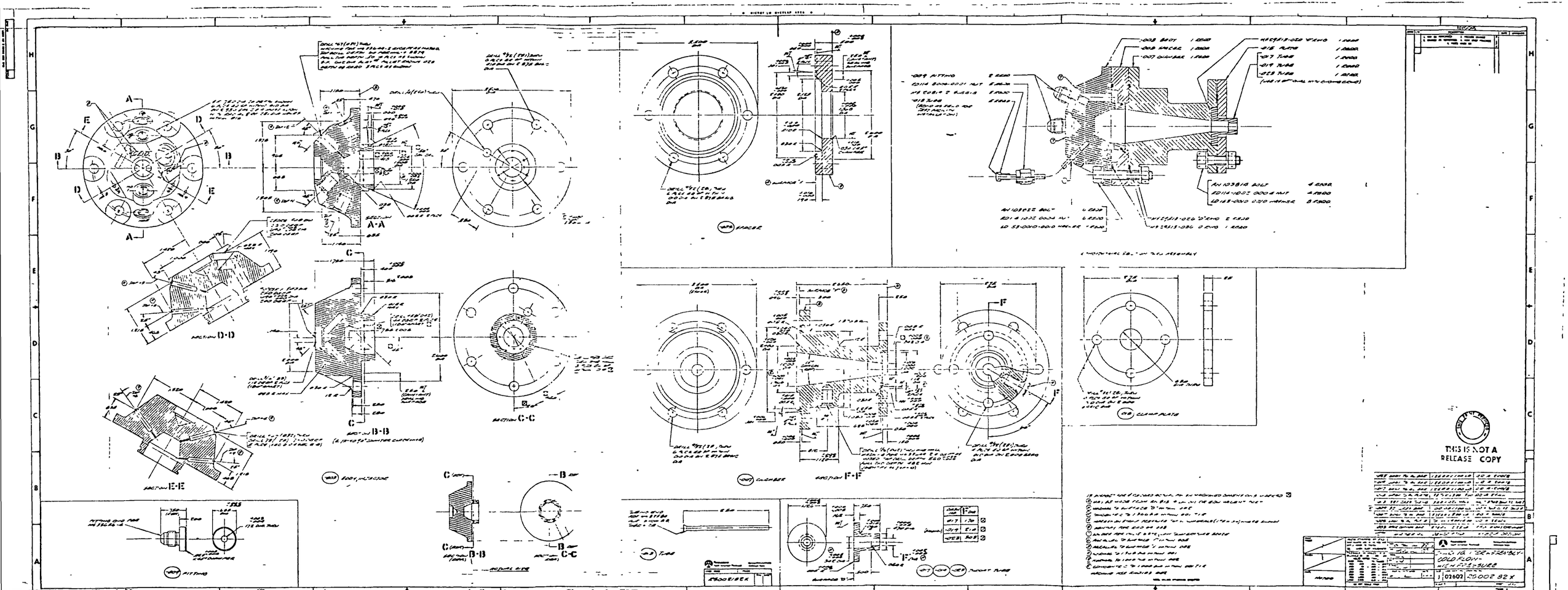
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SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
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Figure 4

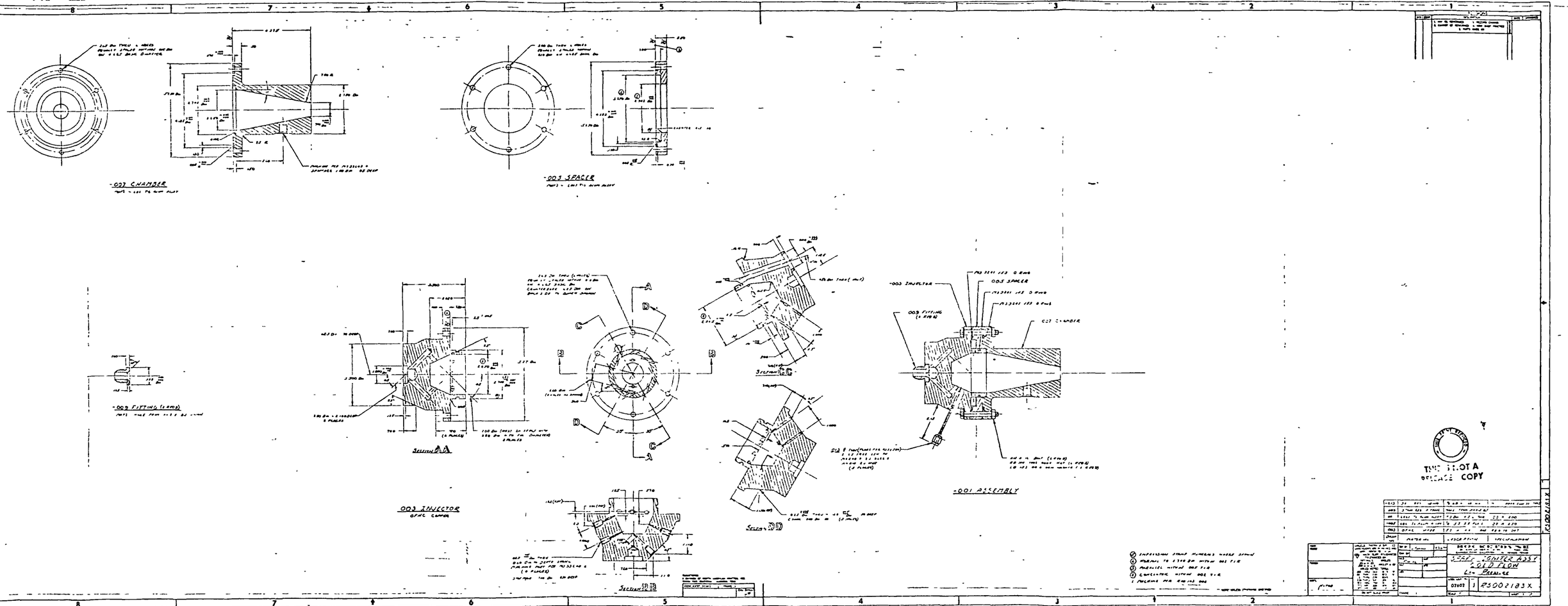
The primary low pressure spark igniter cold flow hardware design is shown on Fig. 5. It is similar in concept to the high pressure ASI type igniter. Design has been completed and fabrication has been initiated. The second low pressure spark igniter cold flow configuration will be a modification to one of the basic ASI designs. Design modifications have been evaluated to change oxidizer orifice impingement angles in the low pressure ASI to affect recirculation and thus mixture ratio in the head end. Design modifications have also been evaluated to change oxidizer and fuel orifice areas in the high pressure igniter to provide a small size low pressure igniter. The design modifications to be adopted will be based upon the initial test results (local mixture ratio and velocity in the baseline ASI configuration).

Cold Flow Test Plan

The objective of the test program is to characterize the flow environment of each injector-chamber hardware combinations so that a rational design approach can be taken in specifying location and power requirements of spark type igniters. The design objective is to maximize life expectancy of the igniter element as well as to provide for ignition reliability. Cold flow simulation techniques will be used to determine mixture ratio and mass flow rate fields. From the mixture ratio and mass flow rate data, ignitability, combustion temperatures and heat transfer conditions can be predicted from available correlations.

These igniter simulation systems will be operated at low (15 psia) or high (100 to 300 psia) pressures at flow conditions simulating the pre-ignition phase of operation. The simulant gas flow rates are based upon an equivalent gas jet momentum flux. This results in the same oxygen flow rate but the helium flow rate is $\sqrt{2}$ times the required hydrogen flow rate for a given mixture ratio. Total equivalent propellant flow rate (O_2/H_2) will be held constant at .04 lb/sec.

The test program will be conducted at the Peroxide Laboratory, Santa Susana Field Laboratory, in which low and high-pressure gas mixing and sampling facilities have been assembled and checked out.


-007 CHAMBER
-003 SPACER
-009 FITTING (LONG)
003 INJECTOR
-001 ASSEMBLY
SECTION AA
SECTION BB
SECTION CC
SECTION DD
-003 INJECTOR
005 SPACER
007 CHAMBER
009 FITTING (LONG)
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SPACE IGNITER ASSY
COLD FLOW
LOX PRESSURE
P5002183X

Figure 5

Facility flowrates will be established for all tests using calibrated (1/2 percent) flow control nozzles (Flow-Dyne) operating with sufficient pressure differential for sonic flow. The simulant gases (oxygen, helium and nitrogen) are supplied from refillable bottles at ambient temperature. Supply pressures and operating chamber pressure are read using precision (1/2 percent) calibrated Heise gauges (12-inch dial). Dynamic pressure measurements are made using MKS-Systems Baratron (Model 778-1122) differential pressure capacitance-type transducer. Helium concentrations are determined using a Gow Mac (model 24-100 and 24-510) thermal conductivity apparatus. Oxygen concentrations are measured using a Beckman (Model 777) oxygen analyzer. The gas sampling apparatus is calibrated using end-point pure gas references with pressure compensation. Readout of concentration measurements is on a Dymec digital voltmeter (Model 2401A).

The test plans for the high pressure 4-on-1 and the two ASI apparatuses are given in Tables 1, 2, and 3. Testing is being postponed for the second low pressure configuration until test results become available.

Approximately 120 sets of data will be obtained for the high pressure 4-on-1 injector. A nominal mixture ratio and chamber back pressure (representative of a pre-ignition condition) will be chosen as a reference baseline. A single axially-oriented pitot probe will be indexed in a cylindrical coordinate system (injector rotatable, probe traverse radial) using five angular positions and three radial positions for 15 sampling positions in a given axial plane. The probe will gather gas samples as well as measure dynamic pressure at each position The axial position of the probe tip with respect to the injector face will be varied by spacing the injector body with boltson intermediate flanges. Measurements will be taken at four axial planes at varying distance from the injector face. Besides varying probe position (in three dimensions) injected mixture ratio and back pressure level will be varied in two increments each from baseline values.

Approximately 36 sample sets are planned for the low pressure (15 psia) ASI type apparatus and an additional 72 sets for the high pressure (100 to 300 psia) ASI type apparatus. The high pressure test series contains twice the number of

TABLE I

TEST PLAN

4-ON-1

(Hi P_c)

Test No.	Inj. MR	Sample Plane	P_c	$\dot{m}_{O_2}$	$\dot{m}_{He}$
1	1.0	1	62*	.020	.028
2	1.0	2	62*	.020	.028
3	1.0	3	62*	.020	.028
4	1.0	4	62*	.020	.028
5	1.5	TBD	62*	.024	.022
6	1.7	TBD	62*	.025	.021
7	TBD	TBD	124**	TBD	TBD
8	TBD	TBD	186***	TBD	TBD

* Corresponds to pre-ignition chamber pressure for 100 psia igniter operation.

** Corresponds to pre-ignition chamber pressure for 200 psia igniter operation.

*** Corresponds to pre-ignition chamber pressure for 300 psia igniter operation.

TABLE II

TEST PLAN - ASI

LOW PRESSURE

Test No.	Inj. MR	Velocity Determinations	P_c*	$\dot{m}_{O_2}$	$\dot{m}_{He}$
1	1.0	---	9.0	.020	.028
2	1.0	A,B,C	9.0	.020	.028
3	1.25	---	9.0	.022	.025
4	1.25	A,B,C	9.0	.022	.025
5	1.50	---	9.0	.024	.023
6	1.50	A,B,C	9.0	.024	.023

TABLE III

TEST PLAN - ASI

HIGH PRESSURE

Test No.	Inj. MR	Velocity Determinations	P_c*	$\dot{m}_{O_2}$	$\dot{m}_{He}$
1	1.0	---	62	.020	.028
2	1.0	A,B,C	62	.020	.028
3	1.25	---	62	.022	.025
4	1.25	A,B,C	62	.022	.025
5	1.50	---	62	.024	.023
6	1.50	A,B,C	62	.024	.023
7	TBD1	---	124	TBD1	TBD1
8	TBD1	A,B,C	124	TBD1	TBD1
9	TBD2	---	186	TBD2	TBD2
10	TBD2	A,B,C	186	TBD2	TBD2

*P_c - Pressure in chamber before ignition $\equiv$ .62 P_c post-ignition.

tests since testing will be done over a pressure range. The hardware for these test series are different but the test approach and procedures are the same and are discussed together. The ASI units feature a doublet oxidizer injector and peripheral tangential fuel injection through multiple (8) orifices. The expected tangential gas swirl precludes axial probing such as in the 4-on-1 apparatus. Thus, gas sampling is accomplished at discrete locations distributed in the intended spark-plug area by using small (1/32" dia) surface openings equivalent in construction to static pressure taps. Peripheral gas velocity will be sampled at several locations using pitot probes (with holes in the side wall), extending a few diameters past the chamber surface and rotated to find the pressure maximum.

The test variables for the ASI-type hardware include injected mixture ratio and pre-ignition chamber back pressure.

The data which will be gathered in this test program will be reduced using modifications of available computer programs. Mixture ratio, mass flow rate, and heat transfer conditions will be calculated. Results will be displayed in graphical format so that important variations are easily discernible.

Judgment will be made concerning expected hardware life expectancy and ignitability to select site locations for spark plug placement based on known materials limitations and ignition requirements.

Exciter Design

Preliminary circuit evaluations were conducted on both inductive and capacitive stored energy systems. Selected for final design of the variable power supply unit was the inductive style. This approach has two distinct advantages in the program:

1) As the final design goal unit (integrated plug/exciter) is to contain a minimum of components for size and weight optimization, it will likely be inductive energy storage; hence basic evaluation of pulse shapes, rise times, etc., can be accomplished early in the program, and
2) Rocketdyne currently has two variable capacitive energy storage consoles, whose application to the different plug styles to be tested will provide comparative information on energy transfer efficiency and plug behavior between the two different energy sources.

The preliminary schematic of the inductive storage power system is included as Fig. 6. The basic operation and elements of the unit are as follows:

1) General - A calibrated energy is stored in fixed indicator L 1 (proportional to the inductor current) during a timed gating interval. At the end of the storage interval the inductor current is switched off and the stored energy is transferred through a step-up transformer to the spark plug gap. Monitor points are provided for charging current (stored energy), and output voltage and current at the spark plug.

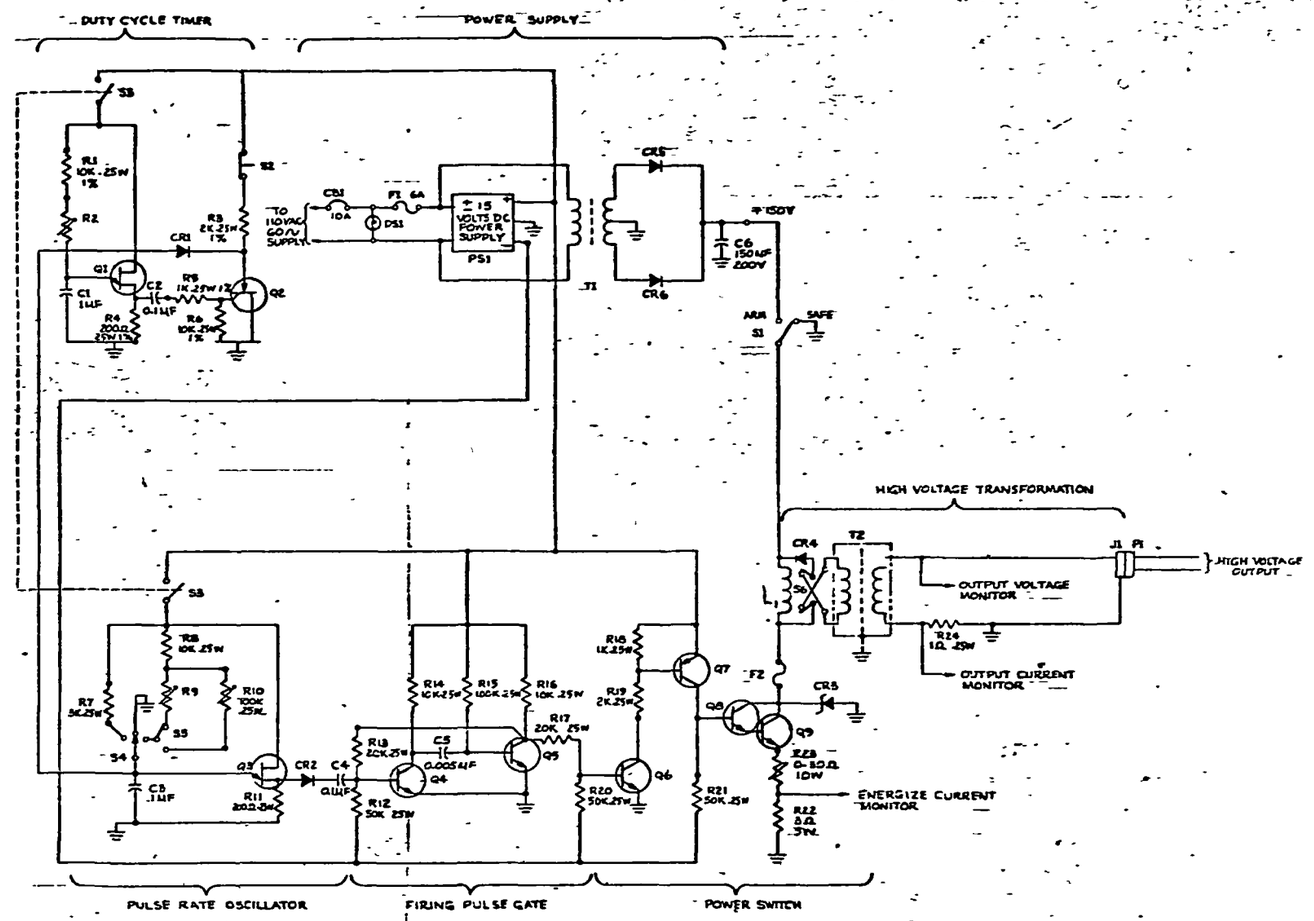
2) Pulse and Gate Circuits - The spark rate is established by a variable frequency relaxation oscillator which drives a monostable multivibrator. The timing pulse generated by the oscillator is shaped by the multi-vibrator to a constant width of approximately 500 microseconds. This shaped pulse provides on-off base current for the power switch (Q8, Q9) in the inductor (L 1) circuit. During the presence of the gate pulse, inductor current flows to a value preset by the variable resistor R23. Upon removal of the pulse, the inductor current is switched off, and the stored energy is transferred to the output by the inductor voltage-reversing action.

3) High Voltage Supply and Output - A rough +150 VDC supply is used to provide fast inductor charging time (for high spark rates). The energy stored in the inductor is not influenced by small voltage variations, being regulated by the constant current supply characteristic of the power transistor switch operated as a high-gain emitter follower.

   Inductor voltage reversal upon removal of the gating pulse forward biases diode CR_4, causing the previously stored energy to transfer to the T2 transformer primary. The T2 secondary is provided with selectable turns ratio taps (not shown schematically) which provides a maximum possible potential of 25 KV (ionization voltage) to be applied to the spark plug.

4) Protective Circuits - A duty cycle timing circuit is included to preclude excessive plug electrode erosion from inadvertent continuous operation. This circuit is another relaxation oscillator driving a latching SCR (Q2). Upon preset timeout, Q2 fires, inhibiting the pulse rate oscillator. Manual reset capability is provided by momentary switch S2.

   In the event the output is unloaded (i.e. by either pressure quenching of the spark gap, or inadvertently), protection for the power switching transistors is provided by zener diode CR3.



COMPONENTS

ITEM NO	PART NO	NAME	MANUFACTURER
R1	RN65C1002F	RESISTOR	MIL-R-10509F
R2			
R3	RN65C2001F		
R4	RN65C2?? ?F		
R5	RN65C1001F		
R6	RN65C1002F		
R7	RN65C5001F		
R8	RN65C1002F		
R9			
R10			
R11	RN65C2002F		
R12	RN65C5002F		
R13	RN65C2002F		
R14	RN65C1002F		
R15	RN65C1003F		
R16	RN65C1002F		
R17	RN65C2002F		
R18	RN65C1202F		
R19	RN65C2301F		
R20	RN65C5002F		
R21	RN65C5002F		
R22	RN65C05R0F		
R23			
R24	RN65C01R0F	RESISTOR	MIL-R-10509F
CR1	UT4005	RECTIFIER	UNITRODE CORP
CR2	UT4020		
CR3	UZ5236		
CR4	UT4020		
CR5	UT4020		UNITRODE CORP
CR6	UT4020	RECTIFIER	
C1	105X9050A2	CAPACITOR	SPRAGUE
C2	104X9050A2		
C3	105X9050A2		
C4	104X9050A2		
C5	472X9050A2		
C6		CAPACITOR	SPRAGUE
S1	MS39058-23	SWITCH	
S2	MS25089		
S3	MS35058-23		
S4	MS25002-1		
S5	MS35058-23		
S6	MS35058-23	SWITCH	
CB1	MS25244-10	CIR BREAKER	
F1	MKP	FUSE HOLDER	BUSSMANN CO.
F2	MKP	FUSE HOLDER	BUSSMANN CO.
T1		TRANSFORMER	
T2		TRANSFORMER	
DS1	95-0410-0931-301	LIGHT	DIALIGHT CORP
Q1	MU4893	TRANSISTOR	MOTOROLA
Q2	T1C45		TEXAS INSTRU.
Q3	MU4893		MOTOROLA
Q4	T1584		TEXAS INSTRU.
Q5	T1584		TEXAS INSTRU.
Q6	T1584		TEXAS INSTRU.
Q7	2N2905		MOTOROLA
Q8	MJ2413		MOTOROLA
Q9	MJ2413	TRANSISTOR	MOTOROLA
J1		CONNECTOR	
P1		CONNECTOR	
PS1	30840	POWER SUPPLY	ACOPIAN

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SCHEMATIC - VARIABLE HI-VOLTAGE POWER SUPPLY

E 02602 RS002496X

RS002496X

5) Variability - The composite exciter circuits provides and will be dial-set calibrated for the following variables:

a) Energy - Controlled by varying inductor current by variable resistor R23. Maximum energy: 320 millijoules.

b) Ionization Voltage - A byproduct of stored energy (inductor voltage characteristics) and further limited and selected by taps on secondary T2.

c) Pulse Rate - Selectable by switch S4 and potentiometers R9 and R10 providing one shot, off and 1 to 1000 pps continuous.

d) Polarity - Reversible using switch S6.

As seen from the preliminary parts list of Fig. 6, two special devices are required - inductor L1 and high voltage transformer T2. Calculations for the energy storage inductor were made from the classic equation ($L = \frac{a^2 n^2}{9a + 10b} \times 10^{-6}$) where inductor parameters are a = diameter, inches, b = length, inches and n = number of turns. In the exciter circuit, with current limited to approximately 4 amperes by the power switch transistors and circuit resistance, a 40 millihenry inductor was chosen to provide a maximum stored energy of 320 millijoules.

Performance requirements for the high voltage pulse transformer were generated and the specification submitted for fabrication bid to several specialty transformer suppliers. Primary specification requirements are:

a) Input - 150 VDC pulse, 50 to 500 usec duration, with ramp time of 10 usec max. 4 amperes max. current, 1000 cps max. frequency.

b) Output - Tap selections of 25 KV, 20 KV, 15 KV and 10 KV; 70 ma max. current.

c) Primary resistance - 0.2 ohms max.

d) Secondary resistance - 300 ohms max.

e) Output pulse rise time - 5 usec max.

f) Power - 100 watts at 25°C.

Responses to the request for quote and procurement will occur during the next report period.

An assembly drawing for the exciter panel was started; finalization awaits receipt of transformer envelope and mounting data. The entire supply will be mounted in a standard 19 inch (48.2 cm) rack-panel approximately 10 inches (25.4 cm) high by 15 inches (38.2 cm) deep.

Exciter Fabrication

All components for the variable high voltage supply unit have been accumulated or procurement initiated. Final sheet metal parts and assembly boards will be released as soon as the high voltage transformer envelope and mounting become firm - anticipated early in the next report period.

The stored energy inductor was fabricated using 490 turns of 18 gauge solid conductor wire on an average 5.5 inch (14 cm) diameter mandrel (14 layers). The inductance measured following fabrication was 41.6 millihenries.

Spark Plug Design

Preparatory to detailing the proposed spark plug designs, two related efforts were conducted. First, an extensive literature search on spark plug development, materials and ceramic-to-metal seals was made. The intent of this research was to take full advantage of historical and state-of-art data, thereby narrowing the selection areas, if possible, to proven reliable concepts.

Secondly, a pre-procurement survey was made and engineering-level discussions were held with potential hardware suppliers. The list of companies contacted is included in Table IV herein. (Those companies indicating interest in fabricating prototype plugs were subsequently invited to bid the job - indicated by asterisk in Table IV.

TABLE IV

SPARK PLUG, CERAMIC-TO-METAL SEAL SOURCES

* Alberox Corp., New Bedford, Massachusetts
Auburn Spark Plug Co., Auburn, N. Y.
AC Spark Plug Division, General Motors Corp., Fling, Michigan
Ceradyne, Inc., Chatsworth, California
* Champion Spark Plug Co., Toledo, Ohio
* Device Seals Inc., North Hollywood, California
* Electro Ceramic Services, Los Angeles, California
* Joslyn Electronic Systems, Goleta, California
* Physical Sciences Corp., Rosemead, California
Prestolite Electrical Products Div. Eltna Corp., Toledo, Ohio
* Reynolds Industries, Inc., Marina Del Rey, California
* Varian Eimac Div., San Carlos, California
Zeller Corp., Defiance, Ohio

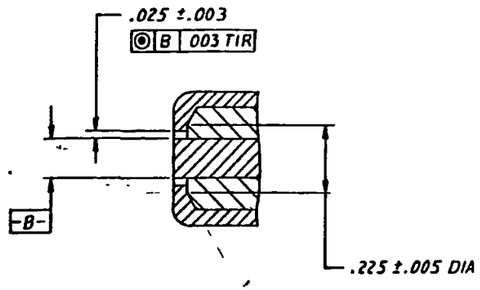
*Interested - invited to bid plug fabrication.

From the literature search and supplier survey, several conclusions were made and dictated features of the bid drawing (Fig. 7). Major decisions were:

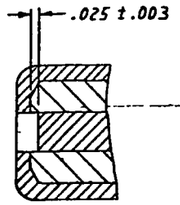
a) Although many ceramic metallizing processes have been used, the Molymanganese process is the most highly developed, satisfies seal strength requirements, and is favored by all companies on the bid list.

b) The insertion of a flexure cup in each ceramic to metal seal area promised the highest confidence in meeting large cycle thermal life. Although certain reports and companies indicated line-to-line metallized and brazed seals might work, plug costs (tighter tolerances) and yield would be adversely affected. It was also apparent that there is no "best" Kovar cup seal design. For this reason, the choice of cup configuration was left to the supplier, with technical concurrence of Rocketdyne.

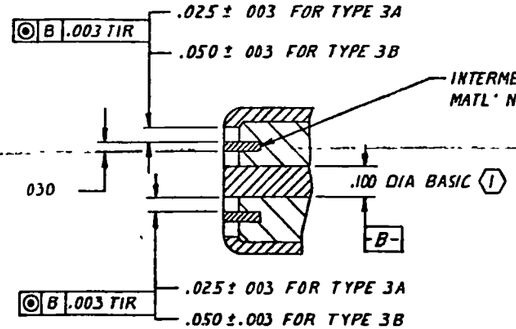
REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
	1. MAY BE REWORKED 2. CANNOT BE REWORKED 3. RECORD CHANGE 4. NOW SHOP PRACTICE 5. PARTS MADE OK — DISPN		



TYPE 1
VIEW A



TYPE 2
VIEW A



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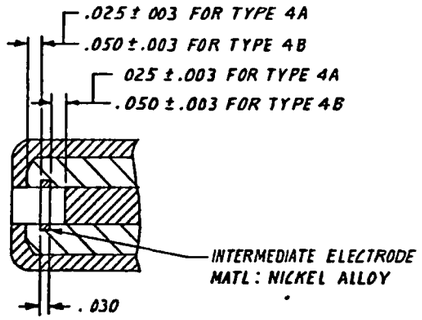

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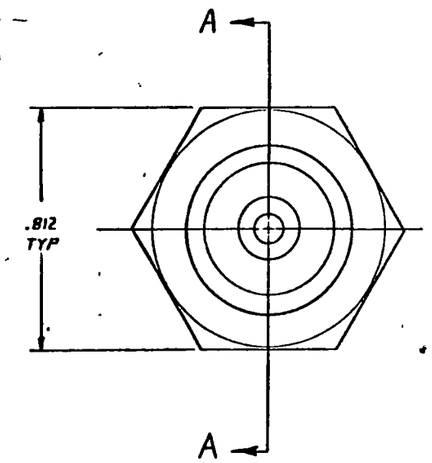

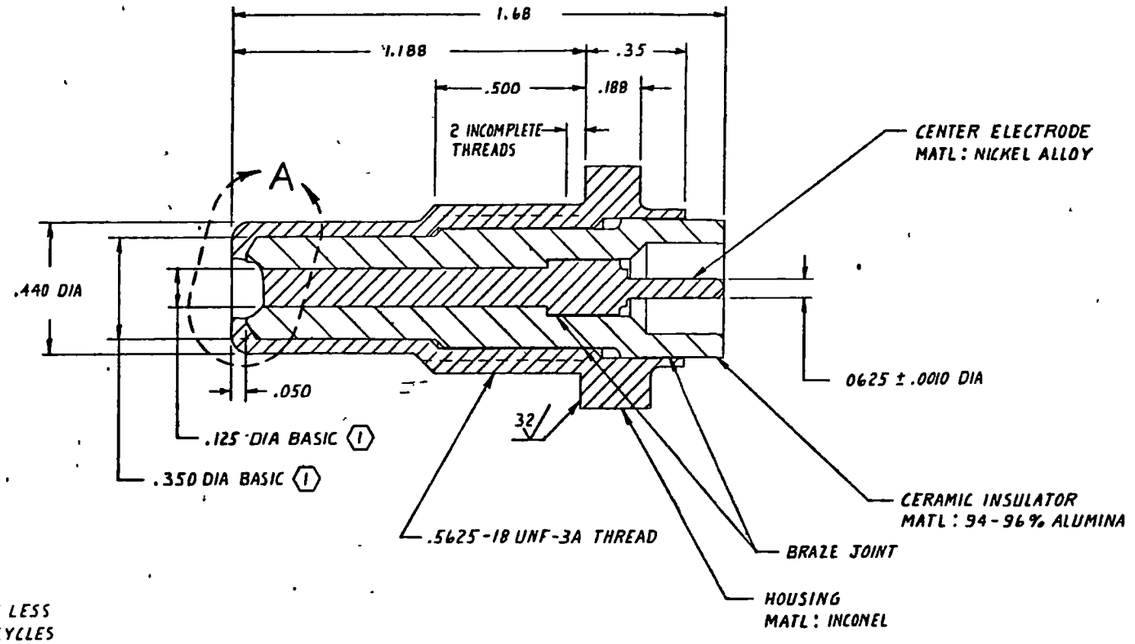

SECTION A-A

REQUIREMENTS

1. THE LEAKAGE RATE THRU ALL BRAZE JOINTS SHALL BE LESS THAN 1×10^{-8} STD CC/SEC OF HELIUM AFTER FIVE CYCLES OF NOTED PRESSURES AND TEMPERATURES
2. OPERATING TEMPERATURE: -260 F TO 600F
3. MAX PRESSURE AT SPARK GAP: 400 PSIA
4. MAX. TEMPERATURE AT SPARK GAP: 1500 F FOR 500 SEC
5. APPLIED ENERGY AT SPARK GAP: 30 MILLI JOULES (APPROX)
6. APPLIED SPARK RATE: 20 KV AT 1000 HZ FOR 2 SECS MAX PER DUTY CYCLE (100,000 DUTY CYCLES)
7. COMBUSTION MIXTURE: GASEOUS HYDROGEN AND OXYGEN

(1) DIAMETRAL CLEARANCES BETWEEN MATING PARTS SHALL BE .002 MAX AT ROOM TEMPERATURE (NON-BRAZED AREAS)

NOTE: UNLESS OTHERWISE SPECIFIED

HEAT TREAT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH	DWN D.FULLER	DATE 8-11-70
FINISH	125/ MACH. SURF ROUGHNESS	CHK	DATE
MATL	TOLERANCES ON: ANGLES ± 0° 30' DECIMALS .XX ± .03 .XXX ± .010 HOLES NOTED "DRILL" OVER THRU TOLERANCE .0000 .0400 + .0015 — .0010; .0401 .1300 + .0030 — .0010; .1301 .2290 + .0045 — .0010; .2291 .5000 + .0060 — .0010; .5001 .7500 + .0070 — .0010; .7501 1.0000 + .0090 — .0010; 1.0001 2.0000 + .0120 — .0010	DSGN	
		MATL	
		STRUCT	
	DO NOT SCALE PRINT	DESIGN ACTIVITY APVD	DATE

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Canoga Park, California
McGregor, Texas

ENVELOPE DRAWING —
APS SPARK IGNITOR

SIZE	CODE IDENT NO.	DRAWING NO.
D	02602	SK 2000

SCALE 4/1 SHEET

SK 2000

Figure 7

c) Electrode material choice is a nickel-alloy (Inconel). The nickel-steel family of alloy possesses reasonable thermal expansion properties compared with alumina dielectrics, thus minimizing seal tension loads. Similarly the nickel alloys provide high work functions as electrodes, have high melting points, and resist sputtering and erosion. Certain electrode materials possible (e.g. tungsten, Rhenium, molybdenum), although having one or more favorable properties surpassing nickel alloys, were discountable due to cost, high oxidation rate, etc.

d) 94-96 percent alumina is the choice insulator material. Not only does this consistency provide high strength and dielectric properties, but, due to large industry use, its processing properties are well known.

e) Variable gap achievement through electroplating was abandoned in favor of machining. Two distinct disadvantages of electrodeposited nickel influenced this change: 1) The difficulty of tight gap control through thick (i.e. greater than 0.005 inch) electro-deposition would require finish machining anyway, and 2) pure or nearly pure e.d. nickel has too high an erosion rate for proper sparking characterization.

The item (e) decision required that two additional half-plug types be created to provide the maximum gap variability within the program cost framework. The Fig. 7 drawing was therefore generated and sent out for bid. Quantity prices were requested for one and two each of the following plug types:

Type	Description	*Variability
1	.025 Surface gap	Progressive machining of outer electrode
1A	.025 Surface gap (Semiconductor)	None
2	.025 Recessed gap	Progressive machining of center electrode
3A	.025 Dual surface gap	Partially variable by machining outer electrode
3B	.050 Dual surface gap	None
4A	.025 Dual recessed gap	Partially variable by machining center electrode
4B	.050 Dual recessed gap	None

*Variability of gap to be accomplished during plug testing at Rocketdyne.

Finalization of the seal design is a portion of the spark plug fabrication task.

Spark Plug Fabrication

Bids from candidate suppliers for one and two each of the half-plug tip configurations were solicited on August 14, 1970, with a response of August 21 requested. Based on expected 5 to 8 week fabrication time, the response date was targeted to permit procurement in time to meet scheduled plug testing. However, despite the preprocurement coordination and follow-up, only one acceptable supplier response was received before 1 September - from Alberox Corporation.

To permit assessment of competitive bids, the target procurement date was slipped to September 4 (mandatory date). This procurement date may result in mid-October plug deliveries and compression of the planned plug characterization test schedule. Effort during the next reporting period will be directed toward finalization of the plug seal design with the selected supplier and realignment of the plug test schedule to compensate for the late-procurement lag.

AUTO-IGNITER

INTRODUCTION

The basic operating principles of the auto-igniter are 1) heating of hydrogen by setting up a resonance condition in a closed ended tube, and 2) introduction of oxidizer and subsequent combustion as the heated hydrogen is mixed with oxygen while the gases are being forced out of the resonance tube by the oxygen (see Fig. 8). The resonance heating in the closed ended tube is achieved by repetitive compression created by the shock structure of the underexpanded hydrogen as it "jumps" the gap between the sonic nozzle and the inlet of the resonance tube. During a Rocketdyne sponsored IR&D task, temperatures as high as 2450°F were achieved by resonance heating using helium as the gas medium (see Fig. 8).

Phenomena Hardware Design

Objectives. The objective of the resonance igniter design is to provide maximum ease and flexibility in changing, during testing, the geometrical variables which affect the performance of this type of auto-igniter, while allowing variations in the thermodynamic properties of the gases involved. Two resonance igniters were designed in accordance with the flowrates, pressures, and temperatures compatible with the operational requirement of the high and low-pressure SSE/APS thrusters; these two igniters will heretofore be named the high and low pressure resonance igniters. Both igniters were designed to auto-ignite and sustain combustion of low mixture ratios of hydrogen and oxygen using hydrogen as the lead gas to set-up the resonance heating process. The hardware design reflects two phases of testing of the resonance igniter which consist of (a) determination of geometry to achieve maximum hydrogen temperature in the minimum amount of time, and (b) introduction of oxygen, ignition, and combustion of hydrogen/oxygen, after the hydrogen as reached a sufficiently high temperature as a result of resonance heating.

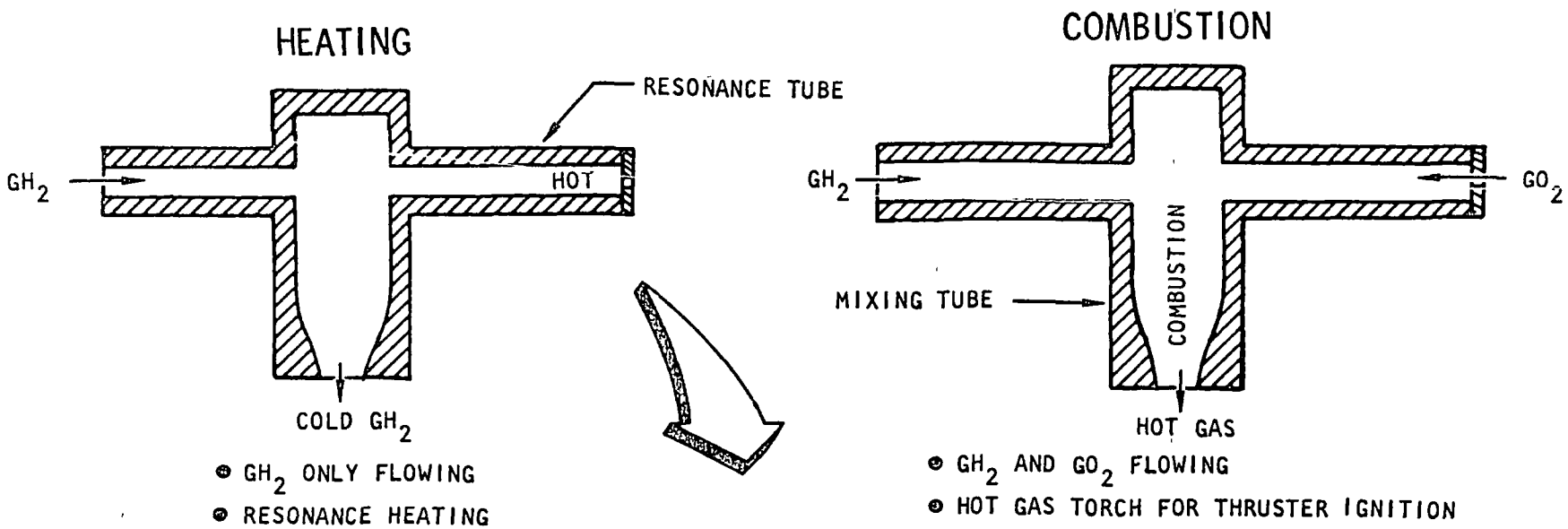
Design Description.

a) Resonance Igniter - Basically the igniter consists of four elements, a feed nozzle, a resonance tube, a mixing chamber, and a restriction located at the end of the mixing chamber (see Fig. 9 and 10).

   1. Materials

      All parts, with the exception of the resonance tube, are stainless steel (CRES). The resonance tubes are made of fused quarts. The main reasons for choosing

O_2/H_2 AUTO IGNITER (RESONANCE)



- GH_2 ONLY FLOWING
- RESONANCE HEATING

- GH_2 AND GO_2 FLOWING
- HOT GAS TORCH FOR THRUSTER IGNITION

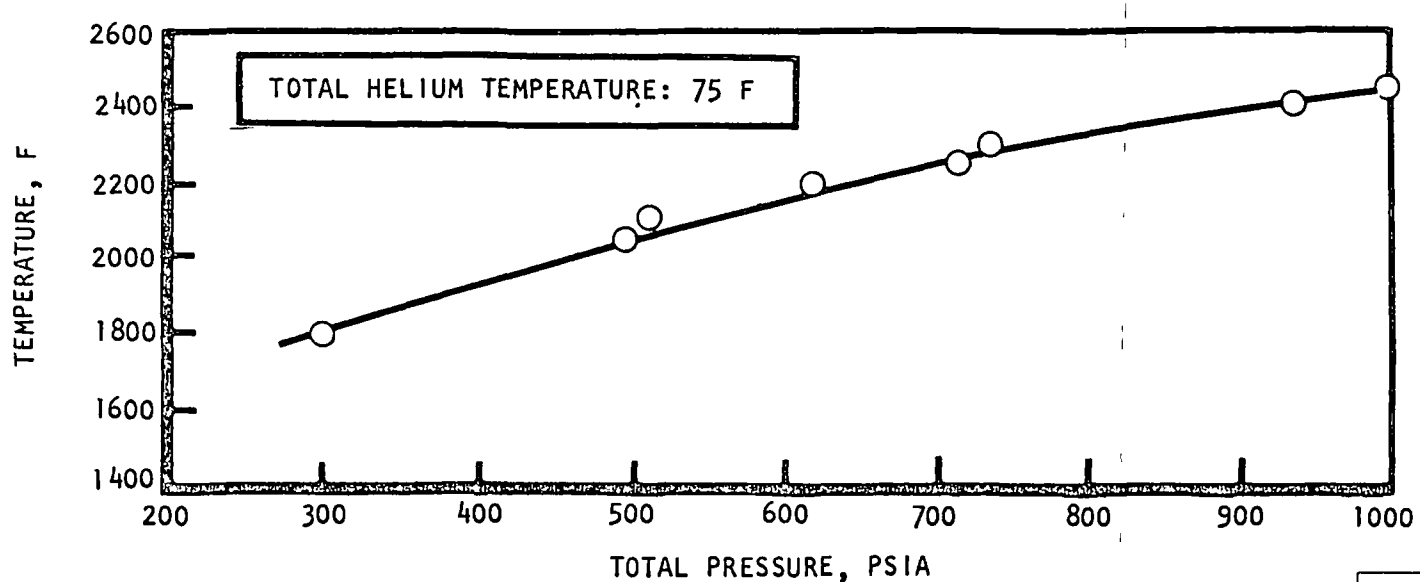


Figure 8

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space shuttle engine
AUXILIARY PROPULSION SYSTEM

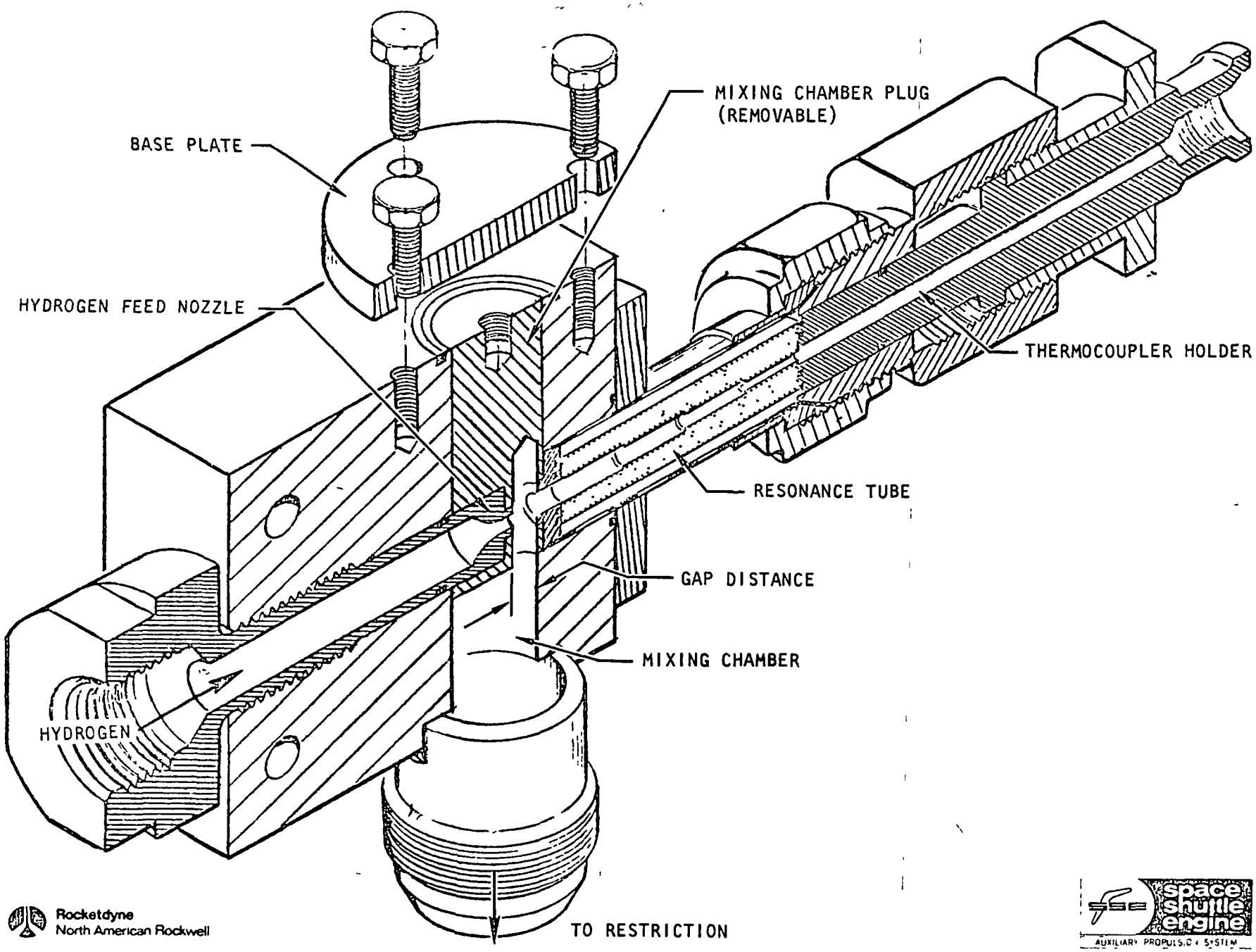

Figure 9. High Pressure Auto-Igniter Test Hardware

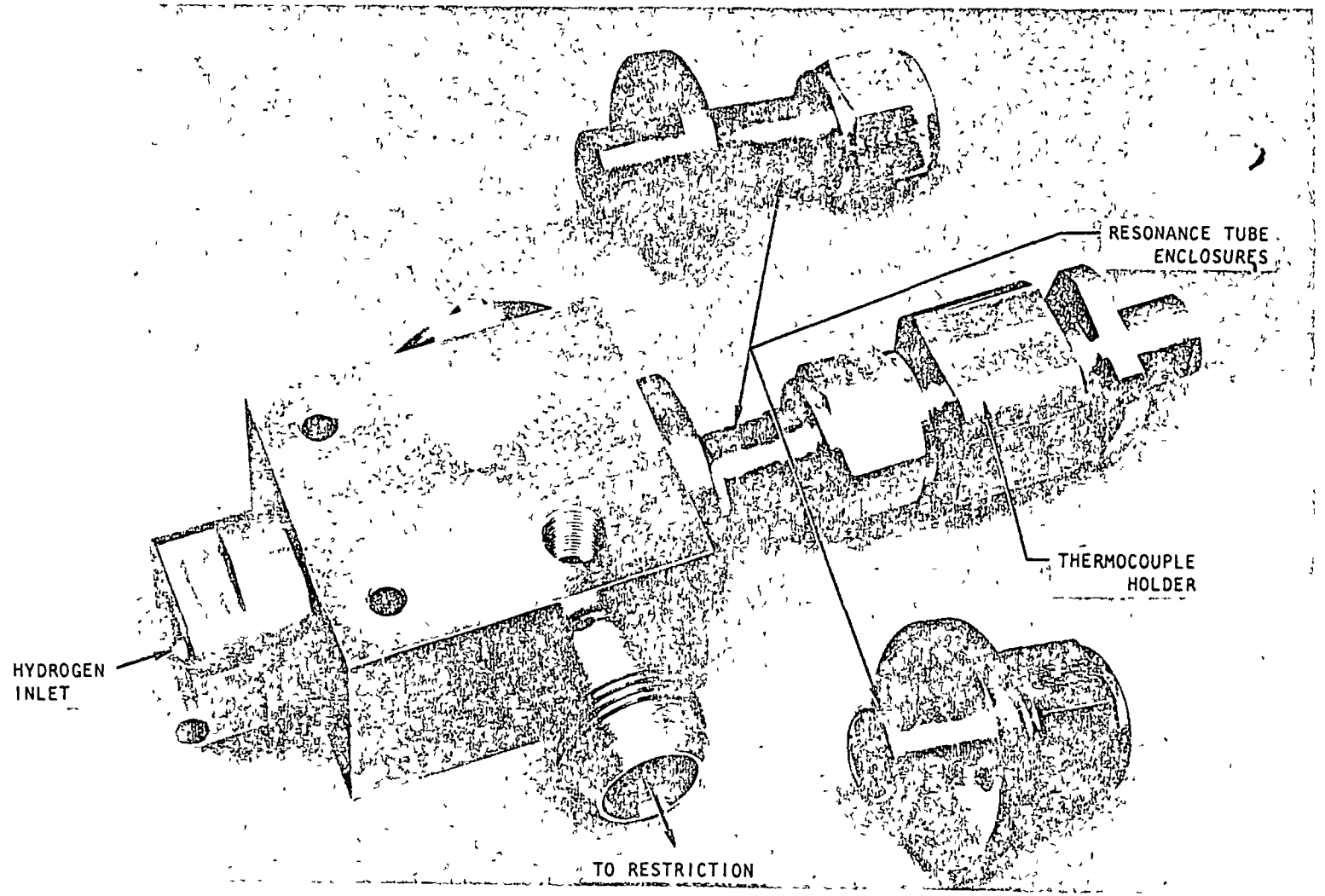

Figure 10. Test Hardware

quartz as the resonance tube material are 1) low thermal conductivity (0.797 Btu/hr-ft-^{o}F or 1.4 W.m/m^{2}.^{o}K), 2) good thermal shock resistance, 3) will sustain heating to approximately 1830^{o}F (1000^{o}C) before undergoing changes in physical properties, and 4) the machining technology is relatively well known compared to other insulating materials investigated. A secondary advantage of quartz is the possibility of using its optical qualities during visual combustion studies, if desired or necessary. For the present time, due to cost considerations, the inside surface of the resonance tube will have a smooth machine finish which is opaque to light transmission. An optical finish can be obtained at a later date.

Feed Nozzle. The feed nozzle supplies hydrogen into the resonance tube and the mixing chamber, and is designed to provide sonic flow at its exit plane. The position of the nozzle exit plane with respect to the entrance plane of the resonance tube can be varied by rotating the feed nozzle assembly. The sonic nozzle is contoured with a circular profile of radius ratio of 5.0 (ratio of contour radius to nozzle throat radius).

The high pressure resonance igniter has a feed nozzle throat diameter of 0.115 in. (.00292 M) to provide a 0.02 lb/sec (.0090 Kg/sec) of hydrogen under chocked flow conditions at a nominal hydrogen total pressure of 375 psia (2.585 x 10^{6} N/M^{2}) and total temperature of 540^{o}R.

The low pressure resonance igniter has a feed nozzle throat diameter of 0.498 in. (.0126 M) to provide 0.02 lb/sec (.0090 Kg/sec) of hydrogen under chocked flow condition at a nominal hydrogen total pressure of 20 psia (1.379 x 10^{5} N/M^{2}) and total temperature of 540^{o}R (300^{o}K).

Resonance Tubes. As stated previously, the resonance tubes will, during the phenomenon testing phase, be made out of fused quartz. A number of configurations have been designed and are currently being fabricated.

The quartz tubes will be inserted into steel tubes to insure alignment and provide a means of securing thermocouples attachment and oxygen valve coupling. The outer surface of the quartz tubes will be secured to the inner surface of the steel tubes by means of a silicone rubber bonding agent (RTV602).

To test the performance of the various resonance tubes, several steel tube holders of different lengths were designed to allow fast configuration changes during testing.

For all resonance tube configurations, the hydrogen inlet diameter (or oxygen exit diameter) will be 30 percent larger than the sonic throat diameter of the feed nozzle. This number was arrived at independently as a result of research performed at NASA and Singer-General Precision, Inc., in attempts to maximize temperatures due to resonance heating.

Two basic resonance tube configurations will be tested on both the high and low pressure igniters. Each of the two basic onfigurations consist of four equal stepped tubes of gradually decreasing diameters. The ratios of overall tube length to the largest diameter (L/D), and the average angles of convergence (θ) are similar to the "optimized" configurations found by the two previously mentioned organizations. The smallest tube diameter coincides with the choaked flow area required for oxygen in order to sustain combustion at an O/F mixture ratio of 1.0.

For the high-pressure ratio igniter, the oxidizer inlet diameter is 0.058 in., (.00147M) to allow a nominal flowrate of 0.02 lb/sec (.0090 Kg/sec) of oxygen at a total pressure of 375 psia (2.585×10^6 N/M) and a total temperature of 540°R (300°K).

For the low-pressure ratio igniter, the oxidizer inlet diameter is 0.250 in., (.00635M) to allow a nominal flowrate of 0.02 lb/sec (.0090 Kg/sec) of oxygen at a total pressure of 20 psia (1.379×10^5 N/M^2) and a total temperature of 540°R (300°K).

The resonance tube configurations to be tested are tabulated below.

Configuration Number	Igniter	L/D	θ (Degrees)
I	Hi P_c	7.75	6
II	Hi P_c	13.2	3
III	Lo P_c	7.75	6
IV	Lo P_c	13.2	3

Mixing Chamber. The mixing chamber can be best described as the volume whose outer surface encloses the feed nozzle exit area, the resonance tube entrance area and the restriction area. Upon ignition of hydrogen and oxygen, mixing and sustained combustion of the two gases occurs within the mixing chamber. During the initial phase of testing, the feed nozzle will be set at various distances from the resonance tube inlet plane to optimize the gap distance in the presence of a particular resonance tube configuration. Once the optimum gap distance has been found, a mixing chamber plug will be drilled out with a diameter equal to this gap distance, and the plug will be inserted into the mixing chamber as shown on Fig. 9. This will be done in order to find out the affect on performance due to the possible base pressure build-up (during initial hydrogen flow) near the closed-end of the mixing chamber.

The mixing chamber will contain two pressure taps, one to provide a means of measuring the base pressure, the other to measure the pressure of the gases as they flow toward the restriction. The latter pressure reading will be instrumental in determining the restriction area to be established during the resonance heating process (hydrogen flow only), and to detect the presence of combustion (simultaneous hydrogen and oxygen flow).

Restriction. The purpose of the restriction is to establish the correct ratio between the hydrogen total pressure and the mixing chamber static pressure. For a given gap distance, this pressure ratio is critical in optimizing the resonance heating rate. Since the exact area of the restriction cannot be calculated a-priori, it will be determined during the geometry optimization testing phase by means of a continuously variable orifice. Once the restriction area has been determined, a fixed sonic throat area nozzle will be made and tested during the ignition/combustion experimental phase.

During the geometry optimization testing phase a remote controlled valve will be placed between the mixing chamber and the vacuum cell. The restriction area will be deduced from measurements of the static pressure in the mixing chamber which will be done by means of a pressure transducer. For a given gap distance the optimum pressure ratio (hydrogen total pressure to mixing chamber static pressure) will be determined by varying the setting of the valve opening and observing the resonance temperature versus time recording.

The high pressure igniter restriction valve will be a 1 in. Annin valve (Model 1660) having a maximum geometrical flow area of 0.1054 in^2 (6.8×10^{-5} M^2). The low pressure igniter restriction valve will be a 2 in. Annin valve (Model 1660) having a maximum geometrical flow area of 1.21 in^2 (7.8×10^{-4} M^2).

Resonance Igniter/Oxidizer Interface. The interface between the igniter and the oxidizer inlet requires special considerations insofar that the end of the resonance tube (where the heated hydrogen resides) should coincide with the oxygen inlet section. Most conventional valves have additional volumes which would, if connected directly to the igniter, modify the required resonance tube configuration, and also introduce surfaces which would be difficult to insulate from heat transfer.

To provide for the correct interface, two Rocketdyne designed solenoid valves will be used to meet the requirements stated above, for both the high and low pressure igniters.

Upon completion of the resonance tube geometry-testing phase, the external surface of the quartz cylinders (which incorporates the optimum high and low pressure resonance tube configurations) will be modified to accommodate the oxidizer solenoid valves.

The oxidizer solenoid valve to be used in conjunction with the high pressure igniter is designated as the Rocketdyne SE-5 valve. The design of the high pressure igniter with the SE-5 valve is shown on Fig. 11.

HIGH PRESSURE AUTO-IGNITER AND OXYGEN VALVE SCHEMATIC

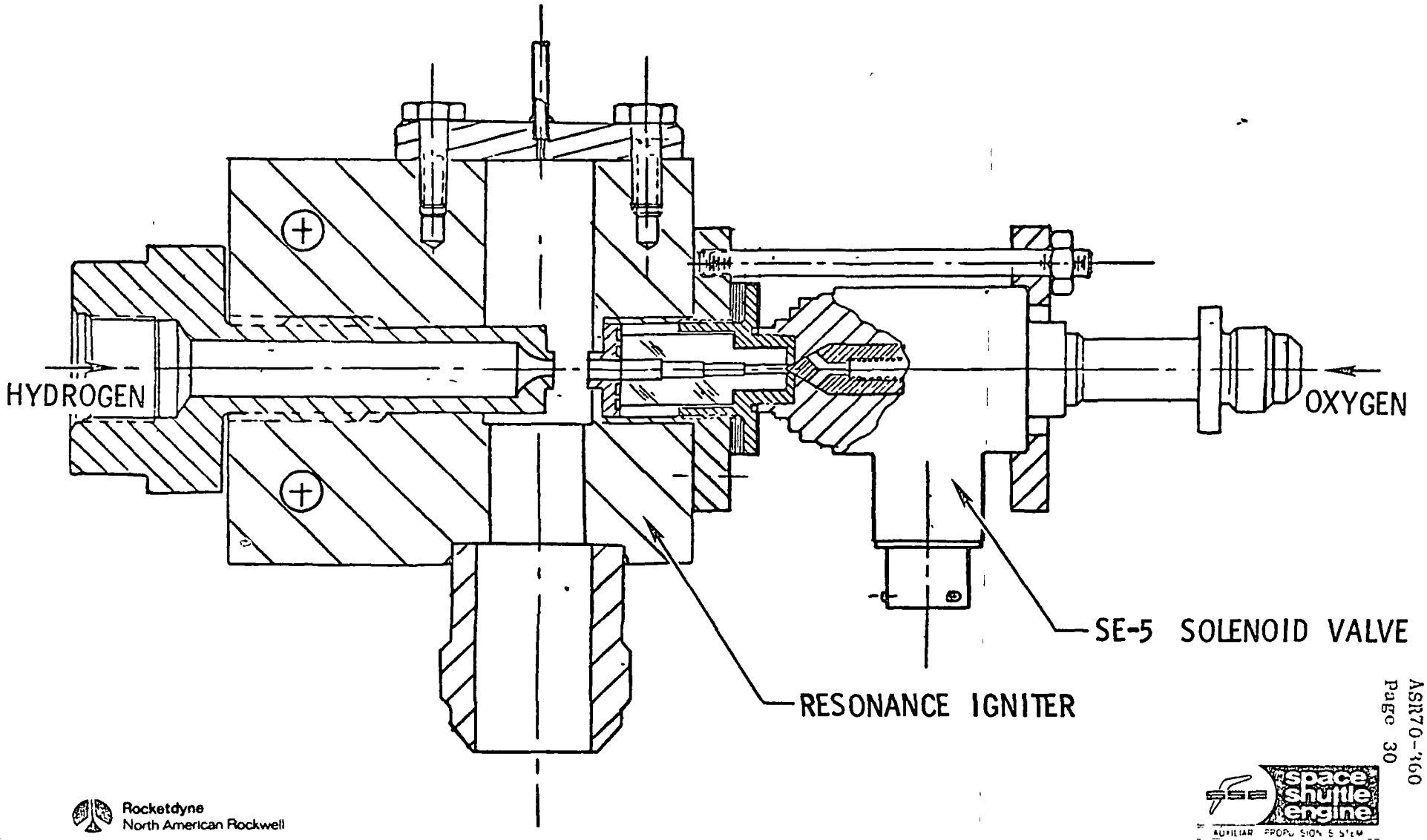

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Figure 11

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The low pressure oxidizer solenoid valve to be designated as the F-1 redundant fuel shut-down valve (Model 558350 - 3 way valve).

The design of the low pressure resonance tube/oxidizer valve interface is currently being completed.

Summary of Design Effort Completed To-Date.

1. High Pressure Igniter Hardware
   a) Resonance tubes: Two configurations have been designed and manufactured.
   b) Igniter hardware: Design and fabrication are completed. (See Fig 9 and 10).
   c) Igniter/oxidizer interface: Design is completed. (See Fig. 11).
2. Low Pressure Igniter Hardware
   a) Resonance tubes: Two configuration designs are completed and manufacturing has been started.
   b) Igniter hardware: Design is completed, and manufacturing has been started. (See Fig. 12).
   c) Igniter/oxidizer interface: Design has been started.

LOW PRESSURE AUTO-IGNITER

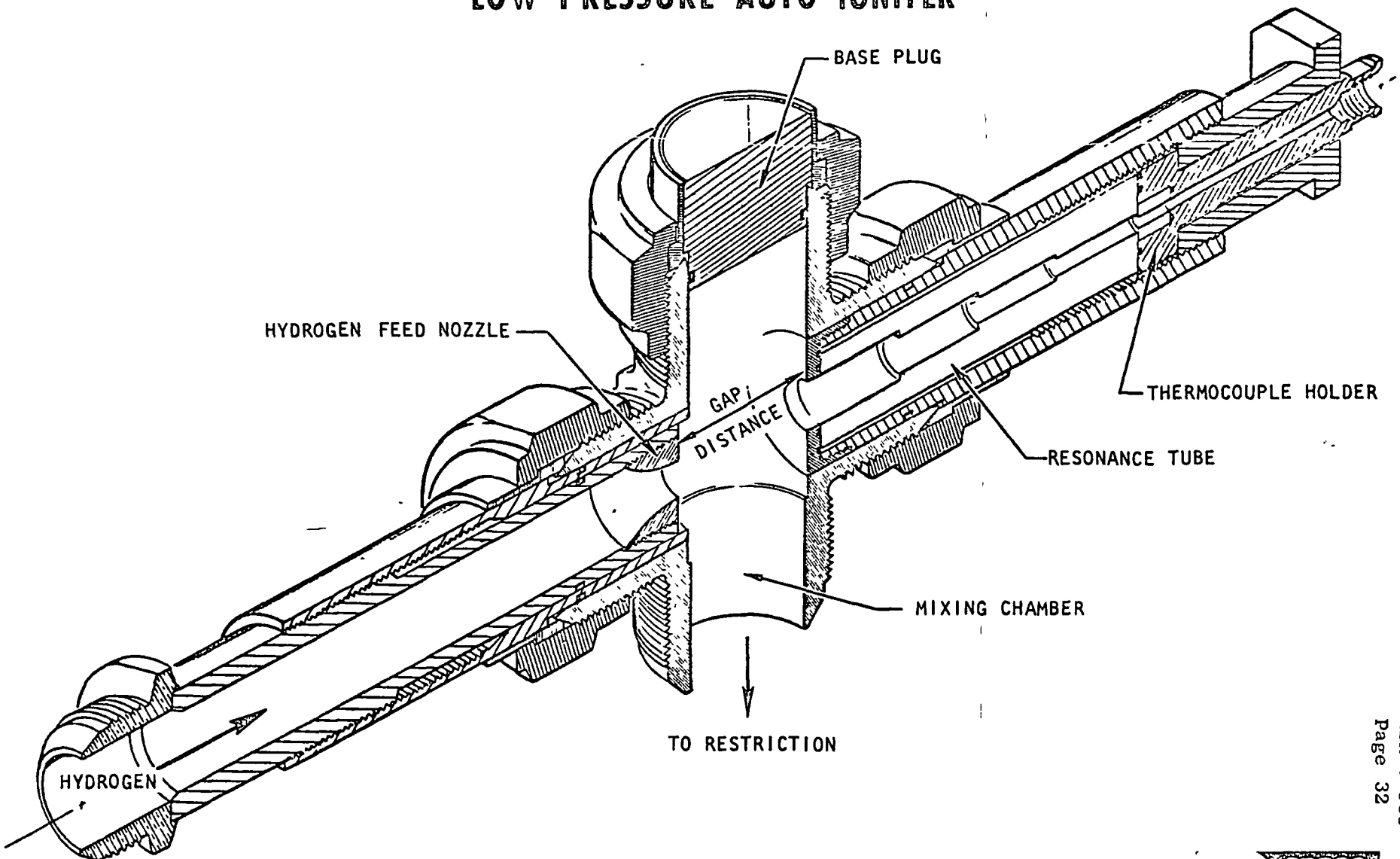

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Figure 12

space shuttle engine
AUXILIAR PROPULSION SYSTEM

TASK II - IGNITER TESTS

During Task II a series of hot-firing tests with gaseous hydrogen-gaseous oxygen propellants will be conducted using the igniters designed and fabricated in Task I. The test plan will be submitted for approval at the end of the fourth month. The test program is comprised of three different types of testing.

The "igniter-only" testing will be conducted on both high and low pressure spark and resonance igniters at the Los Angeles Division to evaluate igniter ignition over the range of propellant inlet conditions. Operating limits including pressure, temperature, and sequencing will be established. These test results will provide design criteria and operating limits for the system design (Task III).

Igniter/thruster igniter tests will be conducted at SSFL CTL-IV to assure that igniter energy is sufficient to provide rapid ignition of the main propellants. These test results will provide thruster transients (ignition delay) data as a function of igniter flowrate and mixture ratio (energy).

Based upon the previous test results, a final test series will be conducted during the ninth month of the program to demonstrate igniter durability. The igniter and test conditions will be specified by NASA and 2500 successive ignition tests will be conducted.

This task was not active during this report period.

TASK III - IGNITION SYSTEM PRELIMINARY DESIGN

During Task III, the results of Task II testing will be used to conduct a preliminary design of a complete ignition system. This effort will be closely coordinated with the NASA Project Manager to ensure the latest available thruster designs are incorporated. The operational limits (propellant inlet temperature and pressure) and the required sequencing and geometric constraints obtained from the Task II tests will be major design input parameters.

The preliminary designs will be completed for the low chamber pressure (15 psia) and the high chamber pressure (300 psia) applications. The designs will include a layout of the propellant plumbing, and the mechanical components, and the operating characteristics and limitations will be delineated. System weight, volume, and propellant usage data will be calculated.

This task was not active during this report period.

PROBLEMS

No major problems have occurred which will effect the overall program technical, schedule or cost status. The overall program schedule and costs are approximately as planned.

Some difficulty was experienced during spark plug procurements due to lack of response from prospective suppliers. To permit assessment of competitive bids, the target procurement date was slipped to September 4 (mandatory date). This procurement date may result in mid-October plug deliveries and compression of the planned plug characterization test schedule. Effort during the next reporting period will be directed toward finalization of the plug seal design with the selected supplier and realignment of the plug test schedule to compensate for the late-procurement lag.

WORK TO BE PERFORMED NEXT REPORT PERIOD

TASK I - IGNITER DESIGN AND FABRICATION

During the next report period Task I efforts will be devoted to high and low pressure spark igniter design and cold flow testing and to high and low pressure auto-igniter design and laboratory testing.

SPARK IGNITER

Cold Flow Testing

Test program planning will be completed early in the report period. The two high pressure and two low pressure spark igniter configurations will be tested and local mixture ratio and gas velocity data will be obtained for candidate spark plug locations.

Exciter Fabrication and Checkout

Pending receipt of procured hardware, the variable power supply will begin fabrication, assembly and checkout. It is planned that the power switching and high voltage section will be "bread-boarded" prior to chassis installation, to enable any unforeseen circuit adjustments. While awaiting this initial breakboard test, several alternate power switch and measuring circuits will be analyzed should their use prove necessary. The breadboard approach will delay final completion of the unit slightly but will not affect spark plug test schedules due to the late plug deliveries.

A J-2 (.050 inch/.127 cm) recessed surface gap plug will be modified for connection to the exciter unit for checkout and initial calibration purposes.

Spark Plug Fabrication

Selection of a spark plug supplier and finalization of the seal design with him will be the top priority item in the next report period. Coordinative effort with the supplier to assure expeditious problem resolution is planned on a twice-weekly basis.

Outline and detailing of the spark plug characterization test matrix will begin during September. In addition to mapping required electrical test points, a photographic method of recording spark visual characteristics will be sought.

AUTO-IGNITER

During the month of September the effort on this task will be devoted to: (1) the completion of the high pressure and low pressure igniter fabrication, (2) minor modification of the existing test facility, and (3) the initiation of testing of auto-igniter testing.

Auto-Igniter Fabrication

High Pressure Igniter Hardware.

a) Igniter/oxidizer interface: Oxidizer valve will be modified and resonance tube holder will be fabricated.

Low Pressure Igniter Hardware.

a) Resonance tubes: Two configurations will be manufactured.
b) Igniter hardware: Fabrication will be completed.
c) Igniter/oxidizer interface: Design will be completed, oxidizer valve will be modified, and resonance tube holder will be fabricated.

Auto-Igniter Facility Build-Up

The facility to be used for the resonance igniter tests is identical to the one used for testing the spark-igniter up to the location of the Marotta valves. The only modification which will be required is the introduction of the resonance igniter and the attending instrumentation. Figure 13 is a schematic of the test facility and the necessary set-ups for testing the high pressure resonance igniter for both the geometry optimization and combustion study phases. The same arrangement will be used for testing the low pressure resonance igniter. The only changes to the arrangement shown on Fig. 13, will be the introduction of an additional regulator in order to reduce the propellant pressures.

Testing is scheduled to start on September 23, 1970. Approximately four weeks of test time will be devoted to the resonance phenomenon investigation; two of these weeks will be used for geometry optimization, and two weeks for the combustion study.

High and Low Pressure Igniter Test Program

Two resonance igniters will be tested:

a) A high pressure resonance igniter (375 psia nominal) (2.585×10^6 N/m^2).
b) A low pressure resonance igniter (20 psia nominal) (1.379×10^5 N/m^2).

Each of these igniters will be tested over a range of pressures (around the nominal pressure) and over a range of temperatures (200°R to 800°R) (111°K to 444°K).

HIGH PRESSURE AUTO-IGNITER TEST FACILITY SCHEMATIC

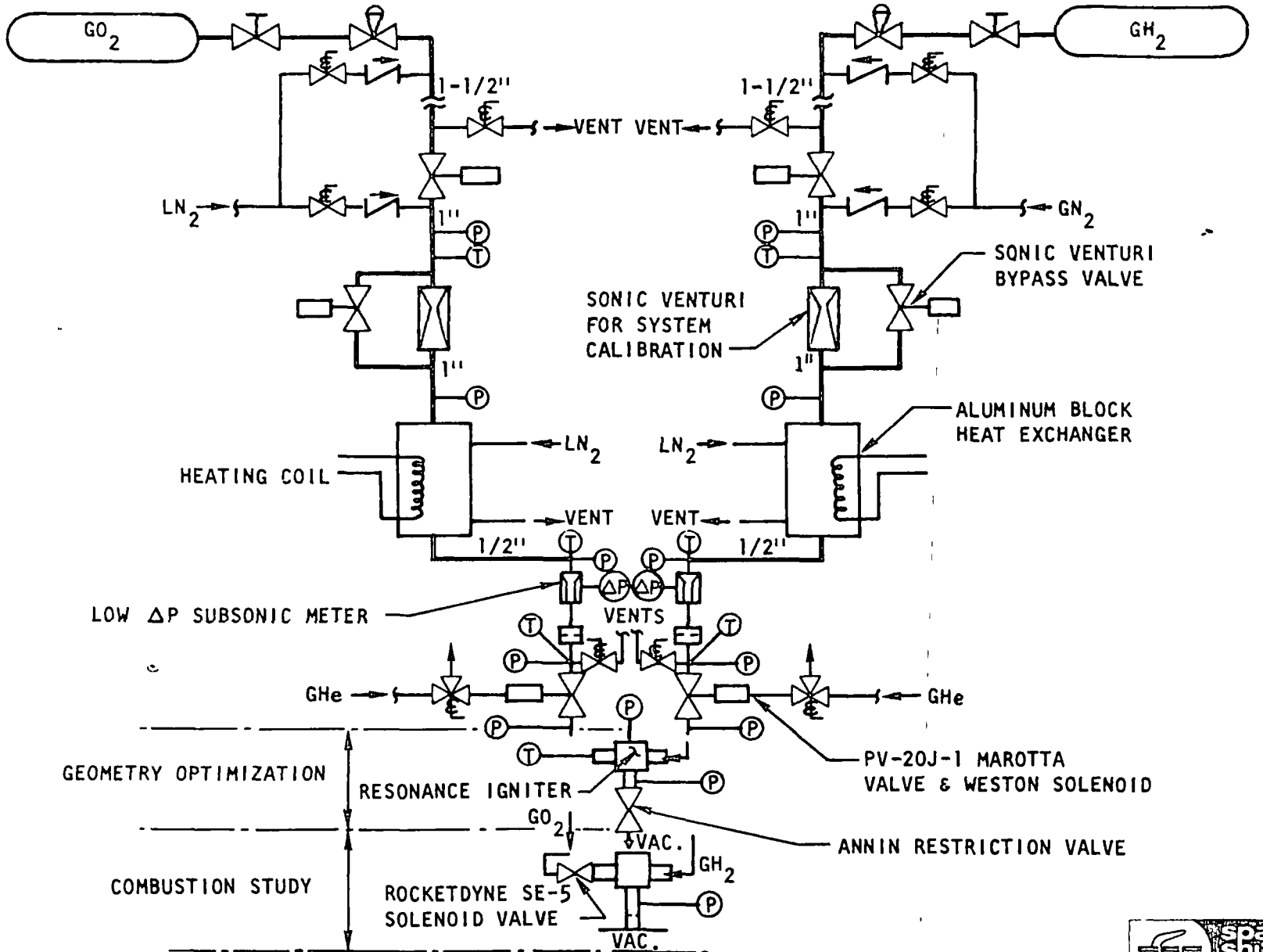

Figure 13

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The test program will be divided into two parts:

a) Geometry optimization of both the high and low Pc resonance igniters, using a single gas (H_2) flowing through the feed nozzle.
   1) Resonance tube configuration
   2) Gap distance
   3) Mixing chamber restriction area

   By optimization it is meant that maximum gas temperature be reached in a minimum time period. Ideally, it is desired to attain a hydrogen temperature of 1200° F (650° C) at the end of the resonance tube, within 10 to 25 milliseconds.

b) Combustion processes involved when oxygen is counterflowing hydrogen. During this part of the study, use will be made of the optimum resonance tube geometries found earlier in this test program.

During the next progress report period it is expected that geometry optimization test phase will be completed.